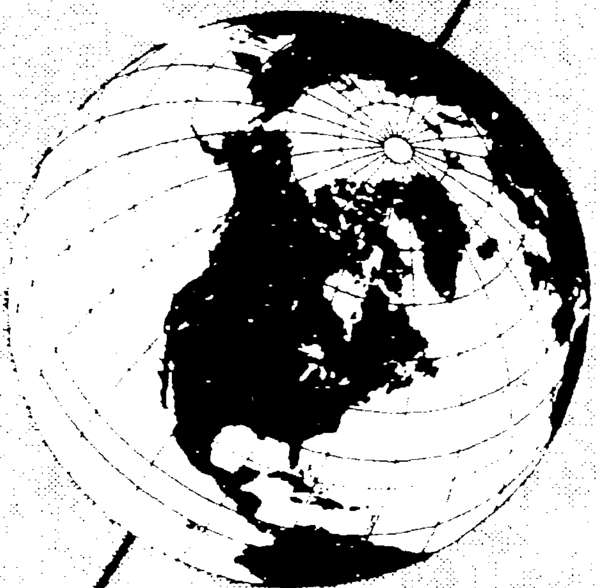
Technical Report 77

SEPTEMBER, 1950

Excavations in Frozen Ground

Igloo Foxholes



U. S. ARMY
SNOW ICE AND PERMAFROST
RESEARCH ESTABLISHMENT
Corps of Engineers

19

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Igloo Foxholes

by Robert Benert

U. S. ARMY SNOW ICE AND PERMAFROST
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Corps of Engineers
Wilmette, Illinois

PREFACE

This is one of a series of reports of work performed on USA SIPRE Project 022.02.011, Excavation in frozen ground (formerly 22-4-2), and covers work accomplished during the winter of 1954-55 at Houghton, Michigan. The feasibility of producing a man-sized cavity (igloo foxhole) beneath a layer of frozen ground was studied under this phase of the project.

The work was performed by Robert Benert, project engineer for USA SIPRE under the direction of W. K. Boyd, chief, Applied Research Branch.

This report has been reviewed and approved for publication by the Office of the Chief of Engineers.

W. L. NUNGESSER
Colonel, Corps of Engineers
Director

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SUMMARY

Tests were conducted near Houghton, Mich., in December 1954 to determine the feasibility of producing man-sized cavities beneath the frozen ground layer. Charges from 0.1-10 lb of low-velocity explosives (Coalite 7S and Gelodyn 1) were fired at depths from 10.5-48 in. in ground frozen to a depth of 6-24 in. The development of these igloo-shaped foxholes by explosive is not recommended since it is not possible to predict accurately the amount of explosive required and the igloo shape is not suitable for combat areas. However, 1 to 2 lb of Coalite 7S is sufficient to produce a 24-in. diam crater in ground frozen to a depth of 1 to 2 ft. The crater can be enlarged easily by excavating the underlying thawed ground.

EXCAVATIONS IN FROZEN GROUND: IGLOO FOXHOLES

by

Robert Benert

INTRODUCTION

During the winter of 1953-54, the Mining Research Corporation, Inc., Mr. Clifton W. Livingston, President, under contract to the Snow Ice and Permafrost Research Establishment, Corps of Engineers, U. S. Army (USA SIPRE) conducted a series of explosive tests in frozen ground near Houghton, Michigan. The results of these tests are presented in SIPRE Report 30, Pt I.[1] One phenomenon reported was the production of an "igloo-type fox hole...made by a gas bubble cavity [formed by an explosion] below the frozen layer; the frozen layer is domed up so that it breaks at the top of the dome, producing an opening large enough for a soldier to crawl into the cavity but leaving the remainder of the dome intact" (op cit., p. 77). The report states: "The domed-up igloo roof is strong enough to be safe without supports. So long as the ground remains frozen, there is little danger of caving" (p. 79). This type of hole is also mentioned briefly by N. B. Lobotskii: "...if a normal charge was placed below the frozen ground or in the unfrozen layer, an ineffective blast resulted. This was especially noticeable in clayey grounds in which man-sized cavities formed below the surface."[2]

At a SIPRE conference with consultants on 20 and 21 December 1954, it was recommended that SIPRE do additional blasting work at the same site as Mining Research Corporation used, to obtain additional information on igloo fox holes.

SITE SELECTION AND PREPARATION

In the fall of 1953, three strips were cleared and leveled for use of the Mining Research Corporation. These strips were located on a hydraulic dredge spoil bank, 9 miles north of Hancock, Michigan. The south strip had not been used for blasting and was, therefore, selected for our use.

In the middle of December, 1954, a 300 by 100 ft area was cleared of snow by a Houghton County road grader. After this initial clearing, the area was kept clear of snow throughout the test season with a small Maxim rotary snow plow.

EXPLOSIVE USED

A low velocity explosive (such as black powder or permissible dynamite) is usually described as having a heaving action while a high velocity explosive (such as

1. C. W. Livingston (1956) Excavations in frozen ground. Part 1. Explosion tests in Keweenaw silt, Snow Ice and Permafrost Research Establishment, U. S. Army Corps of Engineers SIPRE Report 30, Pt. 1, 97 p.

2. N. B. Lobotskii (1943) Vzryvnye raboty (Blasting operations), Stroitel'naia Promyshlennost', vol. 21, no. 9 (text in Russian). SIPRE Translation 23, 1953, p. 1.

60% gelatin dynamite or any military explosive) is described as having a shattering action. A low velocity explosive should be best for forming an igloo fox hole. In order to continue work already done, it was decided to use Coalite 7S (velocity 10,000 ft/sec) which has the lowest velocity of any explosive used by Mining Research Corporation. Coalite 7S was not available immediately; therefore, Gelodyn-1 (velocity 14,000 ft/sec) was used for the first series of shots.

DEFINITIONS*

Critical depth is the minimum depth (measured vertically from the surface to the center of gravity of the explosive charge) at which the energy of the explosion is dissipated into the mass of earth or rock without visibly damaging the surface above the charge.

Critical weight is that weight of a particular explosive which satisfies the critical depth requirement for a particular medium and for a given depth.

The interface ratio as applied to this project, is the ratio of the depth of the center of gravity of the explosive charge to the thickness of the frozen ground. The contact between frozen and unfrozen ground is considered to be an interface.

Optimum weight is that weight of a particular explosive at which the quantity of material loosened by a blast at a given depth or burden is maximum per unit weight of explosive.

PROCEDURE

Drilling.

All blast holes were drilled with a 3-hp Kamo electric auger powered by a 3 kw, 110-volt d-c light plant. Standard commercial ships augers without lead screws were used to produce holes 2 in. in diam and smaller; Kamo augers with rock type bits were used for the 2-1/2 and 5 in. diam holes.

Loading.

All charges were made up in advance by weighing out the correct explosive charge, and taping a single strand of "primacord" to it. The strand of primacord was long enough that at least 1 ft was above the surface when the charge was in place. The charge was lowered into the hole to a predetermined distance from the surface to the center of gravity and the hole was tamped full of dry sand. A no. 6 electric blasting cap was taped to the free end of the primacord.

Firing.

Explosive charges of from 0.1 to 10 lb were fired at 10-1/2 to 48 in. depths to center of gravity. The thickness of the frozen ground varied from 6 in. to 24 in.

The charge was detonated by hooking up a 250 ft long firing line to the blasting cap, testing the circuit with a blasting galvanometer, then firing with a 10-cap twist blasting machine. There were no misfires during these tests.

Excavation.

All excavating was done by hand with a shovel. In many cases, it was difficult to determine the extent of the crater blown in the unfrozen ground. Final cleaning up of the cracks in the frozen ground was done with a household vacuum cleaner.

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* From SIPRE Report 30, Part 1.

Measurements and photography.

A typical cross-section sketch was made of each crater. The average diameter of the breaks in contour of the crater and the depth to these diameters were obtained. A vertical photograph of each crater was taken from a 10 ft high sawhorse set over the crater. In addition, oblique photos were taken of some of the larger holes.

Calculations.

The volume of the craters was calculated by considering each crater to be made up of several geometric figures of revolution (cones, frustrum of cones, cylinders, oblate spheroids, and hemispheres), calculating the volumes of these various segments and adding them.

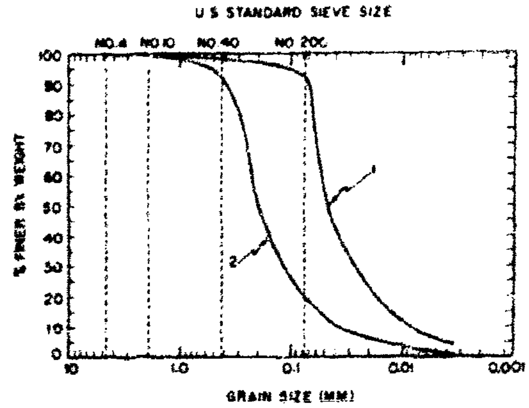

Figure 1. Sieve analyses of typical soils from the test area. Sample 1 - silt (OL) from 0-2 ft depth, nonplastic. Sample 2 - silty sand (SM) from 2-5 ft depth, nonplastic.

RESULTS

General.

Several preliminary shots were made to find the depth of frozen ground and to develop a technique for conducting the tests. Since the depth of the frozen ground was not constant, and increased throughout the season, the center of gravity was kept at constant depth for each series of charges, rather than at the frozen interface. However, the center of gravity of all charges was either in the thawed ground or at the interface (interface ratio equal to or greater than 1). Data on the drilled hole, charge, crater, and a small cross sectional sketch of each crater are given in Table I. Figure 1 shows sieve analyses of typical soils from the test area. Figures 2 and 3 show the crater volume and crater diameter for charges fired. Figures 4, 5 and 6 are photographs of typical craters.

Blast series 1 and 2.

Blast series 1 includes shots 1 through 13. The depth to the center of gravity of all charges was 10-1/2 in., the average depth of frost encountered during the preliminary (unrecorded) shots. The charge weight was varied from 0.2 to 2.8 lb of Gelodyn 1. The average depth of the frozen ground in this series was 8.9 in.
Blast series 2 includes shots 14, 15, and 17 through 25 and is a group parallel to series 1. The depth to the center of gravity was again 10-1/2 in., and the explosive was Coalite 7S. The charge weight was varied from 0.2 to 10 lb. The average depth of the frozen ground was 9.4 in.

None of the charges in these series gave igloo foxholes although in most cases the crater in the unfrozen ground was of larger diameter than in the frozen layer. A comparison of the data from these two series shows that the higher velocity explosive (Gelodyn, blast series 1) gave larger diameter craters than an equal amount of Coalite 7S. The minimum diameter hole that a man can crawl into and enlarge to form a foxhole is about 2 ft. These shots therefore show that if the ground is frozen to a depth no greater than 8 in., a charge of 1/2 lb of Coalite 7S or 1/4 lb of Gelodyn 1, placed at or directly

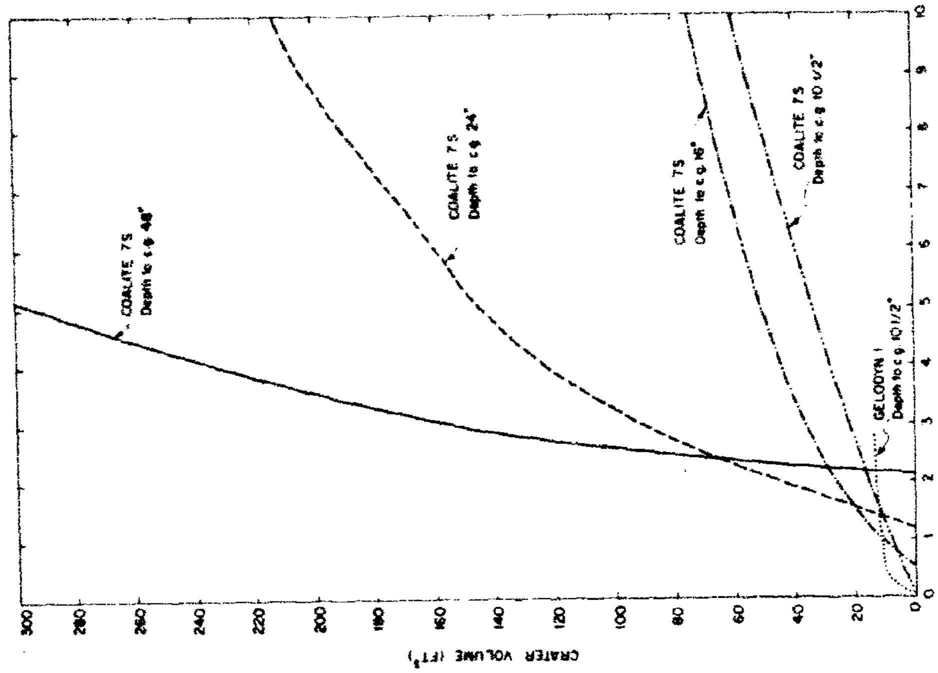

Figure 3. Crater volume vs charge weight.

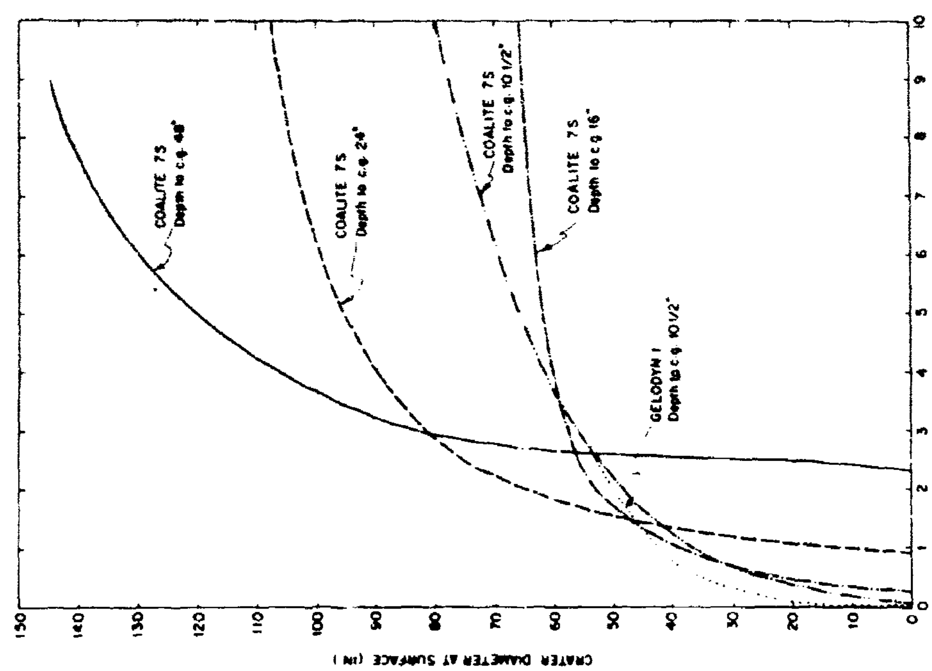

Figure 2. Crater diameter vs charge weight.

Figure 4. Typical small crater obtained in frozen Keweenaw silt.

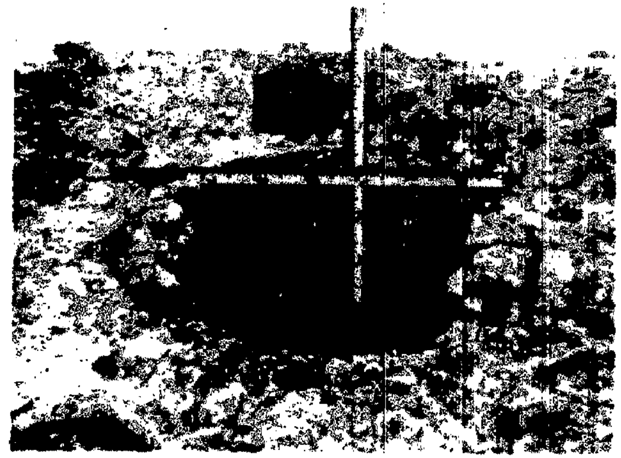

Figure 5. Typical large crater obtained in frozen Keweenaw silt.

Figure 6. Typical igloo foxhole crater obtained in frozen Keweenaw silt.

Table I. Test data

	Hole data		Charge data				
Shot	Diam (in.)	Depth (in.)	Explo.	Depth to top of charge (in.)	Depth to center of gravity (in.)	Wt(lb)	Interface ratio
1	1.5	12	Gelo	9	10.5	0.22	1.2
2	1.5	12	Gelo	9	10.5	0.2	-
3	1.5	12.5	Gelo	8.5	10.5	0.24	1.0
4	1.5	13	Gelo	9	11	0.26	1.3
5	1.5	13	Gelo	8	10.5	0.29	1.2
6	1.5	13	Gelo	8	10.5	0.32	1.75
7	1.5	14.5	Gelo	6.5	10.5	0.47	1.0
8	2.5	13	Gelo	8	10.5	0.62	1.0
9	2.5	13	Gelo	8	10.5	0.78	1.0
10	2.5	13.5	Gelo	7.5	10.5	0.94	1.5
11	2.5	14	Gelo	6	10.5	1.26	1.5
12	2.5	15	Gelo	6	10.5	1.87	1.5
13	2.5	17	Gelo	4	10.5	2.81	1.0
14	1.5	12	7S	9	10.5	0.2	-
15	1.5	12.5	7S	8.5	10.5	0.24	-
16	-	17	Gelo	13	15	3.8	-
17	1.5	13	7S	8	10.5	0.31	-
18	1.9	12	7S	9	10.5	0.35	1.2
19	1.9	12.5	7S	8.5	10.5	0.41	1.3
20	1.9	13	7S	8	10.5	0.5	1.3
21	1.9	14	7S	7	10.5	0.75	1.3
22	1.9	15	7S	6	10.5	1.0	1.0
23	1.9	16	7S	5	10.5	1.5	1.0

Table I. Test data (cont'd)

	Crater data						
Shot	Diam at surface (in.)	Min. diam (in.) frozen ground	Max. diam (in.) unfrozen ground	Depth (in.)	Vol. (ft)	Depth of frozen ground (in.)	Shape*
1	28	16	18.5	15.5	2.3	8.5	
2		No Crater					
3	36	16.5	20	16	5.6	10.5	
4	41			18	9.6	8.0	
5	28	16.0	24	17	5.3	9.0	
6	33	33	33	20	8.2	6.0	
7	41	26	26	26	9.9	10.5	
8	38	25	34	23.5	9.3	10.5	
9	36	32	36	27	11.6	10.5	
10	35	26	34	32	9.5	7.0	
11	39	31	38	32	11.4	7.0	
12	45	40	40	25	11.0	7.0	
13	54	33	38	28	13.8	10.5	
14		No Crater					
15		No Crater					
16	49	31	48	37		7.0	
17		No Crater					
18	28	16	19	19.5	4.7	9.0	
19	29	14	20	20	3.3	8.0	
20	45	30	30	22	9.4	8.0	
21	27	17	29	21	5.2	8.0	
22	27	11	23	24	4.2	10.5	
23	39	22	26	27	8.3	10.5	

* Sketches are not drawn to scale and show shape only.

Table I. Test data (cont'd)

	Hole data		Charge data				
Shot	Diam (in.)	Depth (in.)	Explo.	Depth to top of charge (in.)	Depth to center of gravity (in.)	Wt(lb)	Interface ratio
24	2.5	16	7S	5	10.5	2.6	0.88
25	1.9	14	7S	7	10.5	10.0	1.0
26	1.9	18	7S	14	16	0.5	-
27	1.9	18.5	7S	13.5	16	0.6	-
28	1.9	18.5	7S	13.5	16	0.75	1.2
29	5.0	18	7S	14	16	1.0	1.1
30	5.0	18	7S	14	16	2.0	1.1
31	5.0	19	7S	13	16	4.0	1.3
32	5.0	18	7S	14	16	1.5	1.0
33	5.0	23	7S	9	16	10.0	1.1
34	5.0	22	7S	10	16	6.0	1.1
35	2.5	28	7S	20	24	2.0	1.3
36	5.0	28	7S	20	24	2.25	1.3
37	5.0	28	7S	20	24	2.5	1.0
38	5.0	28	7S	20	24	4.0	1.4
39	5.0	30	7S	18	24	10.0	1.4
40	3.0	28	7S	20	24	1.9	1.4
41	3.0	28	7S	20	24	1.8	1.4
42	3.0	28	7S	20	24	1.7	1.4
43	3.0	28	7S	20	24	1.6	1.2
44	3.0	27.5	7S	20.5	24	1.5	1.0
45	3.0	28	7S	20	24	1.4	1.2
46	3.0	28	7S	20	24	1.3	-

Table I. Test data (cont'd)

	Crater data						
Shot	Diam at surface (in.)	Min. diam (in.) frozen ground	Max. diam (in.) unfrozen ground	Depth (in.)	Vol. (ft)	Depth of frozen ground (in.)	Shape*
24	41	25	31	27	10.8	12	
25	80	65	65	30	60	10.5	
26		No Crater					
27		No Crater					
28	48	23	23	27	9.5	13	
29	50	23	27	32	14.3	14	
30	57	32	46	38	34	14	
31	62	43	60	42	48	12	
32	46	23	36	32	16.7	16	
33	66	54	67	50	75	14	
34	62	44	65	50	66	14	
35	60	13	39	40	17	18	
36	71	59	59	42	71	18	
37	73	56	56	40	61	24	
38	96	80	85	50	125	18	
39	108	108	120	45	213	18	
40	66	50	50	36	43	17	
41	61	52	52	33	40	18	
42	57	42	43	35	29	18	
43	48	30	43	42	26	20	
44	58	12	45	42	23	24	
45	60	11	39	32	10	20	
46		No Crater					

* Sketches are not drawn to scale and show shape only.

Table I. Test data (cont'd)							
	Hole data		Charge data				
Shot	Diam (in.)	Depth (in.)	Explo.	Depth to top of charge (in.)	Depth to center of gravity (in.)	Wt(lb)	Interface ratio
47	5.0	54	7S	42	48	10.0	2.0
48	5.0	53	7S	43	48	9.0	2.0
49	5.0	52	7S	44	48	6.0	2.1
50	5.0	52	7S	44	48	4.0	2.0
51	5.0	52	7S	44	48	3.0	2.0
52	5.0	52	7S	44	48	2.5	-
53	5.0	51	7S	45	48	2.5	1.9
54	5.0	52	7S	44	48	2.6	-
55	5.0	52	7S	44	48	2.7	-
56	5.0	52	7S	44	48	2.8	1.7

below the interface will give a crater of large enough diameter in the frozen ground that a man could make himself a foxhole with a small amount of digging in the unfrozen layer.

Blast series 3.

This series includes shots 29 through 34. The depth to the center of gravity of all charges was 16 in. The explosive used was Coalite 7S and the charge weight was varied from 0.5 to 10 lb. The average depth of frozen ground was 13.8 in.

There was no marked change in the shape of the craters of this series over series 1 and 2, although they are considerably larger. This lack of change is due to the increased depth of frozen ground, which kept the interface ratio more or less constant even though the depth to the center of gravity of the charge was increased from 10-1/2 to 16 in. Again there were no true igloo foxholes although shot 30 did give a domed-up roof which covered only a small portion of the crater. This group of charges showed that with ground frozen to 14 in. in depth a 1-lb charge placed at the frozen ground interface will give a hole in the frozen ground large enough that a foxhole can be dug in the unfrozen soil beneath the frozen layer.

Blast series 4.

This series includes shots 35 through 46. The center of gravity of the charges was at 24 in. depth. The explosive used was Coalite 7S and the charge weight was varied from 1.3 to 10 lb. The average depth of frozen ground was 19.4 in. This group of

Table I. Test data (cont'd)

	Crater data						
Shot	Diam at surface (in.)	Min. diam (in.) frozen ground	Max. diam (in.) unfrozen ground	Depth (in.)	Vol. (ft)	Depth of frozen ground (in.)	Shape*
47	156	156	156	80	575	24	
48	144	144	144	72	450	24	
49	132	132	132	72	375	23	
50	102	102	102	60	235	24	
51	84	56	56	54	100	24	
52		No Crater					
53	58	5	48	60	51	23	
54		No Crater					
55		No Crater					
56	108	36	55	72	143	28	

* Sketches are not drawn to scale and show shape only.

charges gave the first true "igloo-type foxhole" as described by Livingston. However, the unreliability of predicting whether or not an "igloo" will be formed is shown in that 2 lb of explosive (shot 35) gave a completely closed igloo, while 1.9, 1.8, and 1.7 lb (shots 40-42) each gave a straight crater, and 1.6, 1.5, and 1.4 lb (shots 43-45) each gave an igloo hole; 1.3 lb (shot 46) broke the surface of the ground with no crater and so was slightly above the critical weight. This group of charges showed that, with ground frozen to a depth of 20 in., a charge of 1.6 lb placed at or slightly below the interface will give a hole in the frozen ground large enough so that a foxhole can be dug in the unfrozen ground.

Blast series 5.

This series includes shots 47 through 56. The center of gravity of the charges was 48 in. deep. The explosive used was Coalite 7S and the charge weight was varied from 2.5 to 10 lb. The average depth of frozen ground was 24.3 in. Large craters were formed by shots of 10, 9, 6 and 4 lb and were not excavated, as all excavation was done by hand. The results of this series were very inconsistent. One shot of 2-1/2 lb did not give a crater; a parallel shot of the same weight (shot 53) gave an igloo foxhole of 58 in. radius at the surface and a volume of 51 ft^3. Shots of 2.6 and 2.7 lb did not give a crater. A shot of 2.8 lb gave a crater considerably larger than a 3-lb shot although smaller than a 4-lb charge. The data are erratic and demonstrate that an igloo foxhole cannot be

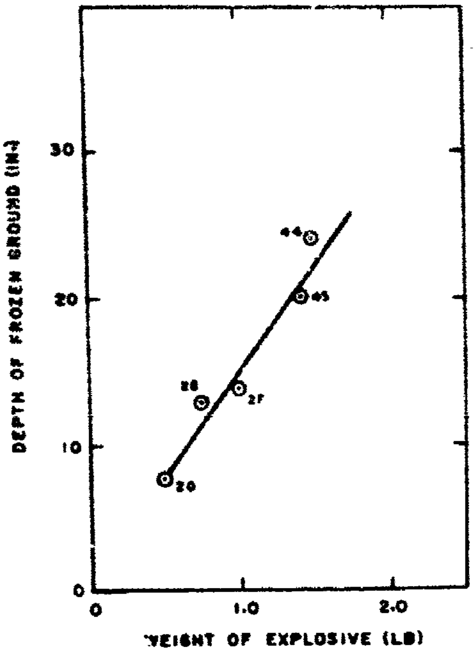

Figure 7. Weight of coalite 7S (placed at the frozen interface) necessary to give a 24-in. diam crater.

definitely predicted. As these charges were placed considerably below the interface, additional information on minimum weight charges placed at the interface for b eaking the frozen ground was not obtained.

DISCUSSION

These tests show that the weight of an explosive charge that will produce an igloo foxhole is critical and cannot be predicted with accuracy, because of natural variations in the test conditions. In addition to the unreliability of getting an igloo-shaped foxhole, it was found that the igloo shape did not give a good useable foxhole for combat areas. If the hole is deep enough so that a soldier can stand upright in it, it is almost impossible to climb out of it in a hurry - especially when wearing bulky arctic clothing and carrying a field pack. Greater protection can be achieved by digging a cave in the side of a straight-sided foxhole under the frozen ground, since the roof is unbroken. For these reasons the igloo foxhole should not be considered for combat use.

However, the results of these tests show the amount of explosive needed to obtain a foxhole in ground frozen to a depth of 24 in. Figure 7 shows the weight of Coalite 7S necessary to break through the frozen ground layer and give a crater at least 24 in. in diameter when the shot is fired at or near the frozen ground interface. The plotted points are actual shots which gave craters of approximately 24 in. diam. The number given near each point is the shot number. As Coalite 7S has a lower velocity than other explosives in normal use, and as it has been found that higher velocity explosives generally give a larger crater in frozen ground, this curve can be used for other explosives with good assurance that the resulting crater will have a diameter greater than 24 in. This crater can then be enlarged in the thawed ground underlying the frozen ground and foxholes of any size can easily be excavated by hand.

CONCLUSIONS

The following conclusions are believed valid for explosions in a frozen fine-grained silt:

1. It is not possible to predict accurately the amount of explosive required to produce an igloo foxhole.
2. The development of an igloo foxhole by explosive is not recommended.
3. With a frost penetration of 2 ft, an explosive charge of less than 2 lb (Fig. 7) placed at the frozen ground interface will break the frozen layer and permit the excavation of a foxhole in the unfrozen layer.
4. Such a foxhole can be enlarged so that the frozen layer forms a roof over a portion of the foxhole.

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